HIGH DUCTILITY, HIGH HOT TENSILE STRENGTH TUNGSTEN WIRE AND METHOD OF MANUFACTURE

BACKGROUND OF THE INVENTION

[0001] This invention relates to a high ductility and high hot tensile strength tungsten wire for incandescent lamp filaments, and a method for manufacturing such a tungsten wire.

[0002] Lamps with an incandescent filament have been known for a long time. In most applications, the filaments are made of a tungsten wire, which is wound into a coil. The dimensions of the coil determine not only the light output of the lamp, but also the optical properties of the light beams emerging from an optical projector system. Such projector systems are found, among others, in headlights of automobiles or slide projectors. Lamps with small filaments have better optical parameters, and allow the formation of a well-defined projected beam, even with small-sized projecting optics. Beside, projector systems not only require small filaments, but also very high lumen output.

[0003] Therefore, coils with extremely small external dimensions are being produced for automotive lamps and projector lamps. The small external dimensions mean that the inner diameter of the coils is also small, in the order of the wire diameter. The inner diameter of the coil largely corresponds to the diameter of the mandrel, on which the filament is wound during manufacturing of the coil. The ratio of the diameter of the mandrel to the wire diameter is termed as the mandrel ratio. In this manner, coils with a small inner diameter will also have a small mandrel ratio. Since the diameter of the filament wire also has a practical lower limit, filaments with small mandrel ratio are necessary for the best possible light efficiency. Further, high light output also requires high filament temperatures. At high temperatures, the sagging of the filament poses serious problems. Therefore, it is sought to manufacture so-called non-sag filaments. The non-sag ability of a filament is closely related to the hot tensile strength of the tungsten wire from which the filament is made. Hot

tensile strength (hereinafter HTS) is measured at 1620 ° C, and desired values are above 0.16-24 N/mg/200 mm.

[0004] During wire production, the wire is annealed (heat treated). This annealing forms the mechanical properties of the wire to enable the assembly of the filaments on an automated mounting machine without breakage. As mentioned above, in some instances the required optical parameters may be obtained only with coils having a very small mandrel ratio, in the order of 2 to 1.5, or even lower. This extreme mandrel ratio requires that the wire remains ductile on room temperature, otherwise the wire may split or break during the winding process, particularly at those parts of the coil, which must endure the largest shaping tension or shaping stress. Ductility of the wire is closely correlated with its cold tensile strength (hereinafter CTS), in the sense that a wire with low CTS has a high ductility, while higher CTS values correspond to low ductility. CTS is measured at room temperature, and desired values for high-end, low mandrel ratio filament wires are between 0.5-0.7 N/mg/200 mm.

[0005] It is known in the art that the ductility of the wire may be influenced with the annealing process. Namely, by the proper selection of times and temperatures of the annealing in combination with the parameters of the wire drawing, the desired ductility (or the CTS) may be accomplished. However, it was noted that HTS values move in tandem with CTS values. With other words, if the annealing were directed towards increasing the ductility of the wire (and thereby lowering the CTS), inevitably the HTS values also decreased. Conversely, when the annealing were directed towards increased HTS values, the ductility of the wire decreased.

[0006] For example, US Patent No. 3,278,281 discloses a process for manufacturing a non-sag tungsten wire. The process involves the preparation of a thorium-doped tungsten alloy, which is swaged and subsequently drawn to wire size. The drawing is done in multiple drawing passes, with multiple annealing steps between the drawing passes. This known process proposes annealing after each five passes, and at temperatures of 1700 ° C.

The resultant wire has outstanding non-sag properties, but operates best in lamps with a relatively low efficiency, and is less suitable for high-end lamps requiring both high temperature and high vibration resistance.

[0007] Another known process for the manufacture of a tungsten wire is disclosed in US Patent No. 4,863,527. This process also involves the swaging of a tungsten alloy rod, and a subsequent drawing to size. During drawing, it is proposed to perform multiple annealing steps, at temperatures around 1560-1620 °C. This known process results in a wire having a relatively low CTS, but high ductility.

[0008] The publication „The Metallurgy of Doped/Non Sag Tungsten" by E. Pink and L. Bartha, spublished by Elsevier Applied Science, London and New York, 1989, further discloses that a tungsten wire need to be annealed during drawing (see pp. 78-79), because the wire strength will increase as the wire is drawn to smaller diameters. According to this literature source, the annealing will reduce the wire ductility. Depending on the final wire size, a combination of anneals is used to optimize the properties of the final wire.

[0009] However, none of the known processes teach a method which would result in a hight HTS of the wire, while reducing its CTS value. Therefore, there is a need for a method which is able to lower the CTS value of a tungsten filament, and accomplishing high ductility of the wire, while maintaining a high HTS value of the same wire. Also, there is a need for a tungsten wire which has a low CTS/HTS ratio. There is also need for a method which accomplishes these results without the use of any additional or specific tungsten wire manufactuing equipment, i. e. which does not require any radical change in exisiting manufacturing facilities.

SUMMARY OF THE INVENTION

[0010] In an embodiment of the present invention, there is provided a method for manufacturing a high ductility and high hot tensile strength tungsten wire for incandescent

lamp filaments. The method comprises the steps of preparing a tungsten alloy, swaging a tungsten rod from the alloy, and drawing the swaged rod to wire size in multiple drawing passes. In the method, the wire is annealed between predetermined draws. It is proposed that an annealing is performed before the final drawing pass, by annealing the wire at a temperature between 1100-1300 ° C.

[0011] In an embodiment of another aspect of the invention, there is also provided a tungsten wire for incandescent lamp filament, which has high ductility and high hot tensile strength. The tungsten wire of the invention has a cold tensile strength - hot tensile strength ratio not exceeding 3.5.

[0012] The disclosed method may be performed with standard tungsten wire manufacturing equipment. By performing the annealing before the last drawing pass, the cold tensile strength - hot tensile strength ratio of the wire is unexpectedly lowered, by lowering of the CTS value, and simultaneously maintaining, in some instances even increasing the HTS value. Accordingly, the filaments made from the proposed tungsten wire are resistant against vibration, tolerate low mandrel ratios, and support high operating temperatures.

BRIEF DESCRIPTION OF DRAWINGS

[0013] The invention will now be described with reference to the enclosed drawings, where

Fig. 1 is a side view of an automotive lamp with a tungsten filament,

Fig. 2 is an enlarged view of a tungsten filament,

Fig. 3 is an illustrative figure explaining the concept of the mandrel ratio,

Fig. 4 is a schematic illustration of a wire drawing process, and

Fig. 5 is another schematic illustration of a step in the tungsten wire manufacturing process.

DETAILED DESCRIPTION OF THE INVENTION

[0014] Referring now to Fig. 1 and 2, there is shown an automotive lamp 1. The lamp 1 has a sealed lamp envelope 2, typically made of glass. 1. The envelope 2 has a sealed inner volume 6 filled with a suitable gas, like argon, krypton or xenon. The inner volume 6 contains a filament 8. The filament 8 is made of a tungsten wire. In certain embodiments, the filament 8 may be single coiled, or double coiled (or coil-coiled), as shown in Fig. 2. Such coiled-coiled filaments are commonly used for higher wattage lamps or high-end lamps. Often, the filament 8 must also be capable of high color temperature operation, i. e. in the heated state, its operating temperature may be above 2900 °K, and in extreme cases it may even reach 3200 °K.

[0015] The filament 8 may contain an aluminum-potassium-silicon (AKS) additive, or other dopants. The dopants are added to the tungsten alloy during the manufacturing of the filament, as will be explained below.

[0016] The filament coil is formed during manufacturing by winding the wire 9 of the filament 8 on a mandrel 10, as illustrated in Fig. 3. Filaments for high-end lamps require low mandrel ratio, in order to obtain proper optical and luminous parameters. The mandrel ratio is defined as the ratio of the diameter d_m of the mandrel to the wire thickness d_w, i. e. the mandrel ratio is d_m/d_w (see also Fig. 3). This requires a wire 9 having a sufficiently high ductility, which corresponds to a relatively low CTS value, preferably as low as 0.7-0.5 N/mg/200mm. In the wire manufacturing method, the ductility needed for a coiling with small mandrel ratio is increased by annealing the wire during the wire production, as will be explained below.

[0017] The wire manufacturing method starts with the preparation of a tungsten alloy, optionally comprising various additives, such as aluminum, potassium, silicon. Further additives may be selected from the group of Th, ThO, YO, LaO, CeO, Re. The beneficial effects of such additives are known in the art, and need not be discussed here.

[0018] Following the alloy powder preparation, the alloy powder is pressed and presintered. The pressing and presintering is also made in a known manner, in order to prepare the alloy powder for the sintering. Thereafter, the alloy powder is sintered with direct current. This is a known process step in powder metallurgy. The specific parameters of the sintering, i. e. temperature, atmosphere composition and sintering current are dependent of the geometrical and other parameters of the furnace. Typical values of sintering current are between 3000 and 6000 A, and the sintering is done in a hydrogen atmosphere. The sintering of a tungsten alloy is also disclosed in US Patents No. 6,066,019, No. 5,742,891 and No. 4,678,718.

[0019] Following sintering, a tungsten alloy wire is formed from the sintered alloy ingot. The forming of a filament is done with known metalworking techniques, e. g. rolling, swaging and wire drawing. The swaging forms a tungsten rod from the alloy, which is suitable for drawing to wire size. During swaging, the tungsten rod may be also annealed and/or re-crystallized. This process step is known in the art.

[0020] The swaged rod is subsequently drawn to wire size in multiple drawing passes. As illustrated in Fig. 4, the diameter of the wire 9 decreases as the wire 9 is forced through a series of drawing dies 11,12,13, of which only three is shown in Fig. 4. (Fig. 4 is not to scale.). Typically, the wire 9 is drawn from the swaged rod to final size in twenty to forty drawing passes, depending on the final wire diameter. With this method, wire diameters between 0.3-0.04 mm are customarily produced. The drawing causes intensive stresses in the crystal structure of the tungsten wire, which is at least partly compensated by annealing the wire between predetermined draws, typically after each 3-4-5 or more drawing passes, depending on the desired result. This annealing may be done by electric heating, or by heating with a gas burner 15, as shown in Figs. 4 and 5. Both types of heating are known in the art.

[0021] The drawings are not made at room temperature, but the wire 9 is pre-heated during the drawing passes, typically to 500-900 °C. The drawing tools contacting the wire 9, i.e. the drawing dies 11,12,13 can also be heated with a suitable known heating equipment (not shown), typically to 300-400 °C.

[0022] In the proposed tungsten wire manufacturing method, an annealing is performed before the final drawing pass. During this annealing, the wire is heated to a temperature between 1100-1300 °C, the actual temperature used depending on the wire diameter. Typically, wires with a larger diameter are annealed at a higher temperature, and thinner wires at a lower temperature. As a result of this annealing just before the final drawing pass, the tungsten undergoes a crystal structure change that improves its ductility, without adversely affecting the final HTS value of the wire. This means that the wire will maintain its good non-sag property, but will not break or split when wound even to small mandrel ratio coils.

[0023] This step of the method is illustrated in Fig. 5, which shows the annealing being performed with a gas burner 16 before the wire 9 is forced through the die 14 during the final drawing pass, as the wire 9 is drawn to final size.

[0024] In a preferred embodiment, as shown in Fig. 5, the final drawing pass after said annealing is done at a different drawing speed than the previous drawing passes. Most preferably, the final draw is done at a slower drawing speed than the preceding draw. For example, the last drawing pass - as indicated by the arrow 22 - may be performed at a drawing speed approx. 65 % of the speed of the last but one drawing, the latter being indicated by the arrow 21. Therefore, the wire 9 is changed from one drawing line to another, as indicated by the arrow 23 in Fig. 5. Of course, it is also possible to make the final drawing on the same drawing line, though it will cause interruptions in a continuous production, hence it is preferable to use another drawing line for the last drawing.

[0025] The proposed method results in a tungsten wire with outstanding non-sag and ductility properties. Due to the fact that the HTS of the wire does not decrease together with the decrease of the CTS value, it is possible to manufacture tungsten wires having a cold tensile strength - hot tensile strength ratio not exceeding 3.5.

[0026] For example, with a 240 mg/200mm size tungsten wire hot tensile strength values of 0.16 N/mg/200 mm were accomplished. For the same wire, a cold tensile strength value of 0.52 N/mg/200 mm was accomplished resulting in a CTS/HTS ratio of 3.25.

[0027] For another wire with a 5.2 mg/200mm size, hot tensile strength values of 0.210 N/mg/200 mm were accomplished. For the same wire, a cold tensile strength value of 0.745 N/mg/200 mm was accomplished, resulting in a CTS/HTS ratio of 3.43. Such thin and ductile wires are well suited for small mandrel ratio coils.

[0028] Some illustrative CTS and HTS values obtained with the method are listed in the table below:

Table I.

Wire Size mg/200 mm	Technology	CTS N/mg/200 mm	HTS N/mg/200 mm	CTS/HTS	Decrease in CTS/HTS ratio, %
5.17	Prior art	0.960	0.217	4.42	
5.17	Annealed *	0.745	0.210	3.43	23
41.60	Prior art	0.723	0.1600	4.52	
41.60	Annealed *	0.607	0.1770	3.43	25
77.60	Prior art	0.610	0.1550	3.94	
77.60	Annealed *	0.570	0.1700	3.35	15
240.00	Prior art	0.551	0.1740	3.75	
240.00	Annealed *	0.520	0.16.00	3.25	14

Annealed * = Annealed before the final drawing pass

[0029] The proposed type of tungsten wire is applicable for all types of lamps, and it is principally recommended for the production of special high-end and automotive lamps with double spiral filaments of small mandrel ratio. A classical example is a 24 V, 21 W stop lamp for automobiles, which is subjected to a high number of switch on - switch off cycles, beside the intensive vibration. The application of this wire will largely reduce the breakage or deterioration of the filaments during manufacture of the coils, and also increases the lifetime of the lamps.

[0030] With the suggested method, the general mechanical properties of the filaments of special incandescent lamps with small mandrel ratio are improved, while it is still possible to produce both the wire and the filaments with standard manufacturing equipment. This means in practice that the production facilities for traditional K, Si, Al doped tungsten wire may be used, while decreasing defect rate of the filaments during production and use. The improved ductility of the wire will result in superior filament winding quality. The wire retains its desired fibrous structure, which is essential for long-life, non-sag filaments.

[0031] The invention is not limited to the shown and disclosed embodiments, but other elements, improvements and variations are also within the scope of the invention. For example, it is clear for those skilled in the art that beside the annealing step before the last drawing pass, a number of further annealing steps may be performed during the various drawing passes, in combination with re-crystallization or similar heat treatments.